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PATENT

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D. Scott
8-17-02

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

In Re Application Of:	)
	) Examiner: unknown
Ram Oron et al	)
	) Group Art Unit: unknown
Application No.: 10/084,796	)
	) Atty. Docket No.: 55219-00002USPT
Filed: February 27, 2002	)
	)
For: Optical Systems	)

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Assistant Commissioner for Patents
Washington, D.C. 20231

Dear Sir:

CLAIM OF PRIORITY UNDER 35 U.S.C. § 119

Under the provisions of 35 U.S.C. §119 Applicants hereby claims the priority the following Israeli patent applications. Certified copies are enclosed.

Israeli Appln. No. 141,727	Filed February 28, 2001
Israeli Appln. No. 144,498	Filed July 23, 2001
Israeli Appln. No. 146,723	Filed November 25, 2001

The Commissioner is hereby authorized to charge any fees that may be required, to Deposit Account No. 10-0447/55219-00002USPT.

Respectfully submitted,

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Attorney for Applicant

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משרד המשפטים
לשכת הפטנטים

This is to certify that annexed hereto is a true copy of the documents as originally deposited with the patent application of which particulars are specified on the first page of the annex.

זאת לתעודה כי רצופים בזה העתקים נכונים של המסמכים שהופקדו לכתחילה עם הבקשה לפטנט לפי הפרטים הרשומים בעמוד הראשון של הנספח.

This 06-03-2002 היום

רשם הפטנטים
Commissioner of Patents

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מספר: Number	141727
תאריך Date	28-02-2001
הוקדם.חדחה Ante/Post-dated	

חוק הפטנטים, התשכ"ז - 1967
PATENTS LAW, 5727-1967

בקשה לפטנט
Application for Patent

(אני, (שם המבקש, מענו — ולגבי גוף מאוגד — מקום התאגדותו
I (Name and address of applicant, and, in case of a body corporate, place of incorporation)

KiloLambda IP Limited
Trident Chambers
Wickhams Cay P.O.B. 146
Road Town, Tortola
BRITISH VIRGIN ISLANDS.

Inventors: Ram Oron
Doron Nevo

בעל אמצאה מכח הדין ששמה הוא
Owner, by virtue of of an invention, the title of which is:

בעברית (Hebrew) **מערכות אופטיות**

(באנגלית) English **OPTICAL SYSTEMS**

Hereby apply for a patent to be granted to me in respect thereof.
מבקש בזאת כי ינתן לי עליה פטנט.

*בקשת חלוקה - Application for Division	*בקשת פטנט מוסף - Application for Patent of Addition	*דרישת דין קדימה Priority Claim		
מבקשת פטנט from Application No. מס' Date מיום	*לבקשה/לפטנט to Patent/Appl. No. ______ מס' Date ______ מיום	מספר/סימן Number/Mark	תאריך Date	מדינת האיגוד Convention Country
*יפוי כח: כללי - עוד יודש P. O. A.: general – to follow				
המען למסירת הודעות ומסמכים בישראל Address for Service in Israel WOLFF, BREGMAN AND GOLLER P. O. Box 1352 Jerusalem, Israel. 91013				

חתימת המבקש
Signature of Applicant

WOLFF, BREGMAN AND GOLLER
by:

היום 27 בחודש 2 שנת 2001
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This form, impressed with the Seal of the Patent Office and indicating the number and date of filing, certifies the filing of the application, the particulars of which are set out above.

*מחק את המיותר Delete whatever is inapplicable

OPTICAL SYSTEMS

מערכות אופטיות

Field of the Invention

The present invention relates to optical systems generally operating with many wavelengths; more specifically, the invention relates to optical systems for transforming an optical ray with a single wavelength into a stabilized series of separated rays, each having a different wavelength.

Background of the Invention

Many optical systems require the use of a series of wavelengths. These different wavelengths are generally referred to as "channels." For example, Dense Wavelength Division and Multiplexing (DWDM) communication systems exploit numerous different wavelengths in order to increase the throughput of the communication system. Other such systems include Differential Absorption Lidar (DIAL) systems, which are used for monitoring pollutants or small quantities of gases in the air. In these systems, the measurement is performed by transmitting rays having a multitude of closely spaced wavelengths, and afterwards detecting the backscattered rays. Generally, one of the rays, having a specific wavelength, is absorbed by a specific substance on the optical track, and the amount of absorption is measured by the ratios of the amplitudes of the backscattered rays.

In general, each single wavelength is obtained from a single source, which is usually a laser source, and the number of required sources is the number of different wavelength channels. Both the central wavelength of each channel and the wavelength variations, are determined by the properties of a specific source. Thus, in order to prevent overlapping of two adjacent wavelength channels, the spacing between these channels must be larger than the wavelength variations or tolerance of each single channel. The wavelength variations result mainly from temperature changes, but are also susceptible to opto-mechanical instabilities and fabrication tolerances. Since the wavelength range of an optical system is generally limited, the wavelength variations in such systems limit the total number of possible channels.

When operating a system wherein each wavelength channel is generated by a different light source or when there is a need in backup sources, an identical light source should be available in stock, which is costly. Alternatively, all of the channels could operate with a similar light source which has a tunable wavelength in a certain range and is fixed to a different wavelength for each channel. Here again, the tunability significantly increases the cost of the light source.

Some systems, in which one fiber laser source provided several wavelength channels with equal spacing between them, have been investigated in the past. However, in such fiber lasers, a single output ray is produced which consists of a multitude of wavelengths. Thus, the different wavelength channels are not separated either spatially or angularly and cannot be separately modulated.

Other known systems applied stimulated Brillouin scattering (SBS) for wavelength conversion. However, such wavelength conversion systems change their properties with temperature or strain, since the frequency shift is dependent on the refractive index (namely, $\nu_B = 2nV_A/\lambda$, where ν_B is the frequency shift, n is the refractive index, V_A is the speed of sound and λ is the wavelength), which in turn changes with either temperature or strain. This instability limits the use of such devices, especially in a cascaded configuration, wherein deviations from the desired frequency shifts are accumulated.

Disclosure of the Invention

The present invention provides a single light source (for example, a laser), from which a series of spatially or angularly separated rays, each having its own wavelength, are produced. The spacings between the wavelength channels can be predetermined and stabilized. Moreover, these spacings remain constant during temperature changes and wavelength variations of the input light source.

The device of the invention is based on non-linear optical arrangements, providing acousto-optical effects and/or SBS, and the like. In these non-linear optical

effects, an incident ray with wavelength λ_i is transformed by means of reflection or scattering into a ray having a wavelength λ_s which is slightly different than λ_i. The wavelength difference λ_s-λ_i is determined by the properties of an acousto-optical device or of the material of an SBS element, and generally changes with temperature or strain. The acousto-optical or SBS device can be in the form of a solid bulk material such as glasses or quartz, a liquid, an optical fiber, or another material having acoustic properties.

In order to obtain a series of separated rays, each having a different wavelength, a cascaded configuration of acousto-optical or SBS devices is utilized. Specifically, the output ray of each of the acousto-optical or SBS devices may serve two functions: First, the ray, or a part of it, may serve as an output wavelength channel of the system; second, the ray, or a part of it, may serve as an input wavelength to another acousto-optical or SBS device, in order to obtain the next wavelength in the series. Such a cascaded configuration may be repeated many times. To compensate for the power losses in the system which arise due to scattering, and the imperfect efficiency of the various components, it is possible to add optical amplifiers next to (either before or after) each acousto-optical or SBS device, or next to a series of a few such devices.

The embodiments proposed and presented herein minimize the temperature dependence of the system, allowing it to operate with nearly fixed spacings at a wide temperature range. These embodiments include the combination of SBS devices and acousto-optical devices, whose wavelength spacings each vary differently (e.g., one increases and the other decreases) with temperature. Similarly, two or more SBS devices, composed of two or more different materials, some having a refractive index which increases with temperature (positive d*n*/dT) such as quartz or BK7 Schott glass, and others having a refractive index which decreases with temperature (negative d*n*/dT), such as FK52 or PK51A Schott glasses, may be used. In this

manner, the total wavelength spacing remains fixed although the individual spacings change with temperature.

Another embodiment of the invention exploits both the temperature and the strain dependence of the refractive index. Here, an optical fiber is wound on a spool. Temperature changes cause two effects: first, the refractive index of the optical fiber changes with temperature according to the composition of the fiber material; second, the strain induced on the fiber, and thereby again the refractive index, changes as the spool expands or contracts with temperature. By means of a proper selection of spool material composition having different expansion coefficients, the expansion, and thereby the strain, is controlled independently of the fiber material. Thus, the two effects (strain and temperature dependence) are designed to cancel each other, leading to a nearly fixed wavelength spacing despite changes in temperature.

The cascaded system is capable of creating a series of hundreds, or even thousands, of wavelengths. The spacings between every two neighboring wavelengths can be predetermined by a specific acousto-optical or SBS device, so that the series of wavelength may have either equal, or different, predetermined and constant, spacings. The system can operate either with a continuous wave (CW), single pulse, or repetitive pulses (RP).

Each output ray, which is spatially separated from the other rays and has a specific stabilized wavelength, can be separately modulated by using a dedicated modulator. Alternatively, the input ray or groups of output rays can be modulated together by the same modulator, to obtain a broadcast-like transmission.

Thus, the present invention provides an optical system for connecting an input ray of light having a single wavelength into a plurality of spatially or angularly displaced output rays, each having a different wavelength, the system comprising an array of a plurality of acousto-optical and/or stimulated Brillouin scattering (SBS) devices in optical communication with each other, whereby variations in the

wavelength of said input ray or in temperature or strain of said devices will cause the wavelengths of said output rays to uniformly vary, thus maintaining constant intra-wavelength spacings between said output rays.

Brief Description of the Drawings

The invention will now be described in connection with certain preferred embodiments with reference to the following illustrative figures so that it may be more fully understood.

With specific reference now to the figures in detail, it is stressed that the particulars shown are by way of example and for purposes of illustrative discussion of the preferred embodiments of the present invention only, and are presented in the cause of providing what is believed to be the most useful and readily understood description of the principles and conceptual aspects of the invention. In this regard, no attempt is made to show structural details of the invention in more detail than is necessary for a fundamental understanding of the invention, the description taken with the drawings making apparent to those skilled in the art how the several forms of the invention may be embodied in practice.

In the drawings:

Fig. 1 is a schematic illustration of a Stimulated Brillouin Scattering device;

Fig. 2 is a schematic illustration of a Stimulated Brillouin Scattering device along with an optical circulator;

Fig. 3 is a schematic illustration of a Stimulated Brillouin Scattering device along with an optical circulator and an optical amplifier;

Fig. 4 is a schematic illustration of cascaded Stimulated Brillouin Scattering devices composed of spooled optical fibers, along with optical circulators;

Fig. 5 is a schematic illustration of cascaded Stimulated Brillouin Scattering devices composed of two different materials, along with optical circulators;

Fig. 6 is a schematic illustration of cascaded Stimulated Brillouin Scattering devices composed of two different materials, along with optical circulators and optical amplifiers;

Fig. 7 is a schematic illustration of an acousto-optic wavelength-shifting device;

Fig. 8 is a schematic illustration of an acousto-optic wavelength-shifting device along with an optical amplifier;

Fig. 9 is a schematic illustration of cascaded acousto-optic wavelength shifting devices;

Fig. 10 is a schematic illustration of cascaded acousto-optic wavelength shifting devices along with optical amplifiers;

Fig. 11 is a schematic illustration of an Optical Parametric Oscillator (OPO) device;

Fig. 12 is a schematic illustration of a combination of OPO devices and either cascaded SBS devices or cascaded acousto-optic wavelength shifting devices;

Fig. 13 is a schematic illustration of a system for obtaining a multitude (10) of separated rays, each having each a different wavelength, out of a single input wavelength, and

Fig. 14 is a schematic illustration of a system for obtaining a multitude (10) of separated output rays, each having a different output wavelength, each of which is modulated by a separate modulator, out of a single input wavelength.

Detailed Description

Reference is now made to Fig. 1, which is a schematic illustration of a stimulated Brillouin scattering (SBS) wavelength displacing device 2. An incident ray of wavelength λ_0 propagates from left to right towards an SBS device 2 made of a material 4, which material could be constituted by an optical fiber, a bulk material, a liquid, or other optical material. Due to SBS, a reflected ray with a slightly different wavelength λ_1 emerges back from the SBS material 4.

Fig. 2 shows a schematic illustration of an SBS device 2 with an optical circulator 6, in which, similar to the device of Fig. 1, an incident ray of wavelength λ_0

propagates from left to right and passes through the optical circulator 6, towards the SBS material 4. Here again, a reflected ray of wavelength λ_1 is created. The optical circulator 6 does not transmit the reflected ray, but rather reflects it to a different path, schematically shown as a downward direction.

An embodiment also including an optical amplifier 8, is shown in Fig. 3. Here, the incident ray (at the left) of wavelength λ_0 has relatively low power. Thus, it is propagated through optical amplifier 8, which could be an optical fiber, a bulk material or other optical material, to obtain a ray having the same wavelength but higher power. This higher power ray is then incident on an SBS device 2, similar to that shown in Fig. 2.

Fig. 4 is a schematic illustration of a cascaded system according to the present invention, comprising a plurality of SBS devices 2. Each output ray, having a specific wavelength emerging from an SBS device 2, serves both as one of the output rays for the cascaded system, and as a source ray for the next SBS device. In this manner, multiple rays, each having a distinct wavelength, are obtained. Each of the individual SBS devices 2 is composed of an optical fiber wound around a spool 10. In the embodiment of Fig. 4, temperature stabilization is obtained by the proper design and selection of the fiber material parameters (mostly temperature dependence of the refractive index) and the spool materials (mostly expansion coefficients) and their dimensions.

Fig. 5 is a schematic illustration of a cascaded configuration of SBS devices 2, wherein alternating devices 2 are composed of two different materials 4, 4′, one having an increasing refractive index with temperature, and the other having a decreasing refractive index with temperature. In this embodiment, temperature constant displacements or spacings are obtained.

Fig. 6 shows a cascaded configuration similar to that of Fig. 5, albeit with additional optical amplifiers 8 in the SBS devices 2. Other numbers and placements of amplifiers 8 along the ray paths are also possible.

Fig. 7 illustrates an acousto-optical wavelength-shifting device 12, in which an input ray of wavelength λ_0 is incident upon an acousto-optical material 14. The scattered or reflected ray, propagating from right to left, has a slightly different output wavelength λ_1.

A similar acousto-optical wavelength shifting device 12, with an additional optical amplifier 16 for the input ray, is shown in Fig. 8. Here, the incident ray (at the left), having a wavelength λ_0, has relatively low power. Thus, it is propagated through an optical amplifier 16 to obtain a ray having the same wavelength but higher power. This higher power ray is then incident on an acousto-optical wavelength-shifting device 12, similar to that shown in Fig. 7.

Fig. 9 is a schematic illustration of a cascaded configuration of SBS devices 12, comprising a multiplicity of the devices shown in Fig. 7. Each output ray, having a specific wavelength emerging from an acousto-optical wavelength shifting device 12, serves both as one of the output rays for the cascaded system, and as a source ray for the next acousto-optical wavelength shifting device 12. In this manner, multiple rays, each having a distinct wavelength, are obtained.

Fig. 10 shows a cascaded configuration similar to that of Fig. 9, with an additional optical amplifier 18 in each of the individual acousto-optical wavelength shifting devices. A combination of acousto-optical wavelength shifting devices, with and without optical amplifiers, is also possible.

Fig. 11 is a schematic illustration of an optical parametric oscillator (OPO) 20. Here, an incident ray with wavelength λ_0 is transformed into a ray having a different wavelength λ_1. The wavelength change, in this embodiment, can be significantly larger than that obtained using SBS or acousto-optical devices 12.

Fig. 12 illustrates a system having a combination of OPOs 20 and acousto-optical wavelength shifting devices 12 or SBS devices 2. Here, a single input ray, of wavelength λ_0, is used. The ray is first split into three ray portions λ_0', λ_0'',

λ_0'''. The first portion λ_0' is applied directly into a SBS device 2 or an acousto-optical wavelength-shifting device 12, to obtain a multiplicity of rays having the wavelengths λ_1-λ_3. The second ray portion λ_0'' is first transformed by an OPO 20 to a ray having wavelength λ_4, which in turn is incident on another SBS device 2 or an acousto-optical wavelength-shifting device 12, to obtain a multiplicity of rays having wavelengths λ_5-λ_7. The third portion λ_0''' is first applied directly into a SBS device 2 or an acousto-optical wavelength-shifting device 12, to obtain a multiplicity of rays having wavelengths λ_8-λ_{10}; these rays are then transformed by an OPO 20 to obtain output rays having wavelengths λ_{11}-λ_{13}. Other combinations of OPO 20, SBS devices 2 and acousto-optical wavelength shifting devices 12 are also possible.

Fig. 13 is a schematic illustration of a system 22 according to the present invention, wherein a single input ray of wavelength λ_0 is transformed into a series of separated rays having different output wavelengths; in this specific embodiment, ten wavelengths λ_1-λ_{10}. The system 22 may include cascaded SBS devices 2 or cascaded acousto-optical wavelength shifting devices 12, or a combination of those with OPOs 20. Also, the input wavelength λ_0 may be equal to one of the output wavelengths λ_1-λ_{10}.

In Fig. 14, there is illustrated a system 22, wherein a single input ray having wavelength λ_0 is transformed into a series of separated rays having different output wavelengths as shown in Fig. 12, but each of the output rays is modulated by a modulator 24. When all of the output rays are modulated, the number of modulators is the same as the number of output rays. Here again, the system 22 may include cascaded SBS devices 2, cascaded acousto-optical wavelength shifting devices 12, or a combination of those with OPOs 20. Also, the input wavelength λ_0 may be the same as that of one of the output wavelengths λ_1-λ_{10}.

It will be evident to those skilled in the art that the invention is not limited to the details of the foregoing illustrated embodiments and that the present invention

may be embodied in other specific forms without departing from the spirit or essential attributes thereof. The present embodiments are therefore to be considered in all respects as illustrative and not restrictive, the scope of the invention being indicated by the appended claims rather than by the foregoing description, and all changes which come within the meaning and range of equivalency of the claims are therefore intended to be embraced therein.

WHAT IS CLAIMED IS:

1. An optical system for converting an input ray of light having a single wavelength into a plurality of spatially or angularly displaced output rays, each having a different wavelength, said system comprising:

an array of a plurality of acousto-optical and/or stimulated Brillouin scattering (SBS) wavelength displacing devices in optical communication with each other,

whereby variations in the wavelength of said input ray or in temperature or strain of said devices will cause the wavelengths of said output rays to uniformly vary, thus maintaining constant intra-wavelength spacings between said output rays.

2. The system as claimed in claim 1, further comprising an optical circulator located along the input and output paths of the rays to and from said wavelength displacing devices, for reflecting said output rays in directions different than the directions of said output paths.

3. The system as claimed in claim 1, further comprising an optical amplifier located along the path of said input ray.

4. The system as claimed in claim 1, wherein at least a part of an output ray from one of said wavelength displacing devices is utilized as an input ray to another of said devices.

5. The system as claimed in claim 1, wherein said SBS device is composed of a wound optical fiber.

6. The system as claimed in claim 1, wherein said wavelength displacing devices are composed of different materials, one of said materials having an increasing refractive index with temperature change, and one having a decreasing refractive index with temperature change.

7. The system as claimed in claim 1, wherein an output ray for a first one of said wavelength displacing devices constitutes a source ray for a second one of said devices.

8. The system as claimed in claim 1, further comprising an optical parametric oscillator (OPO) located along the input and/or output paths of at least one of said wavelength displacing devices.

9. The system as claimed in claim 1, further comprising at least one modulator for modulating an output ray.

10. An optical system as claimed in claim 1 for connecting an input ray of light having a single wavelength into a plurality of spatially or angularly displaced output rays, each having a different wavelength, substantially as hereinbefore described and with reference to the accompanying drawings.

for the Applicant:

WOLFF, BREGMAN AND GOLLER

by:

Fig. 1

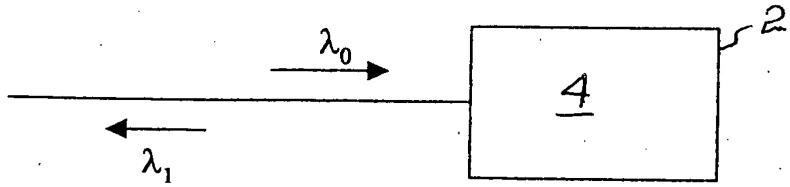


Fig. 2

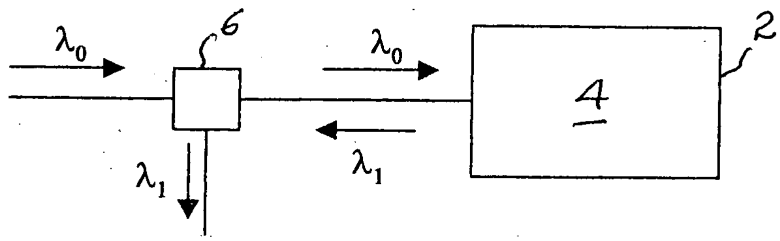


Fig. 3

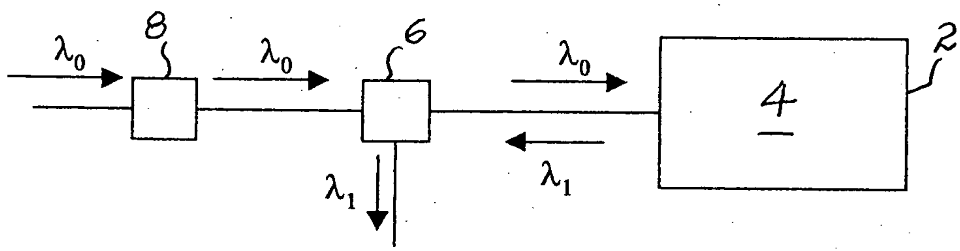
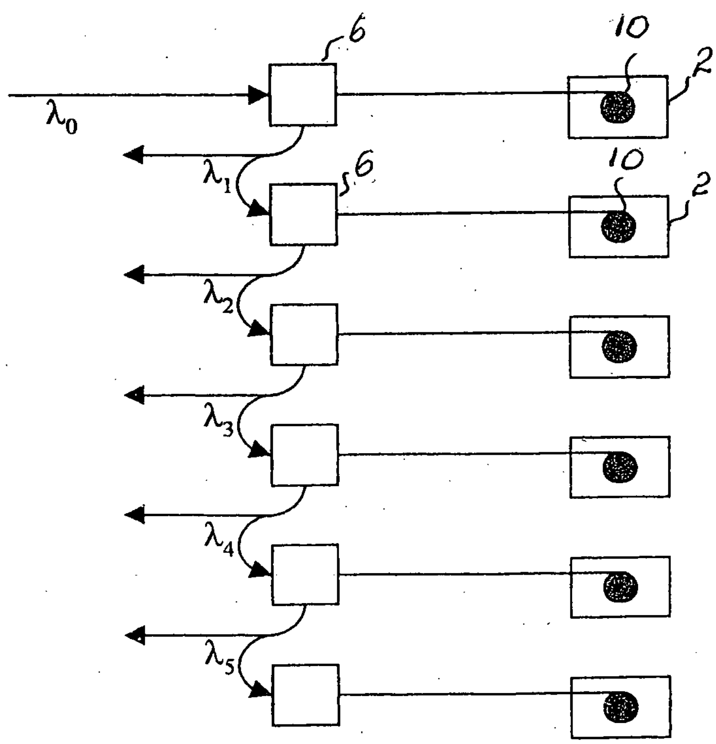


Fig. 4



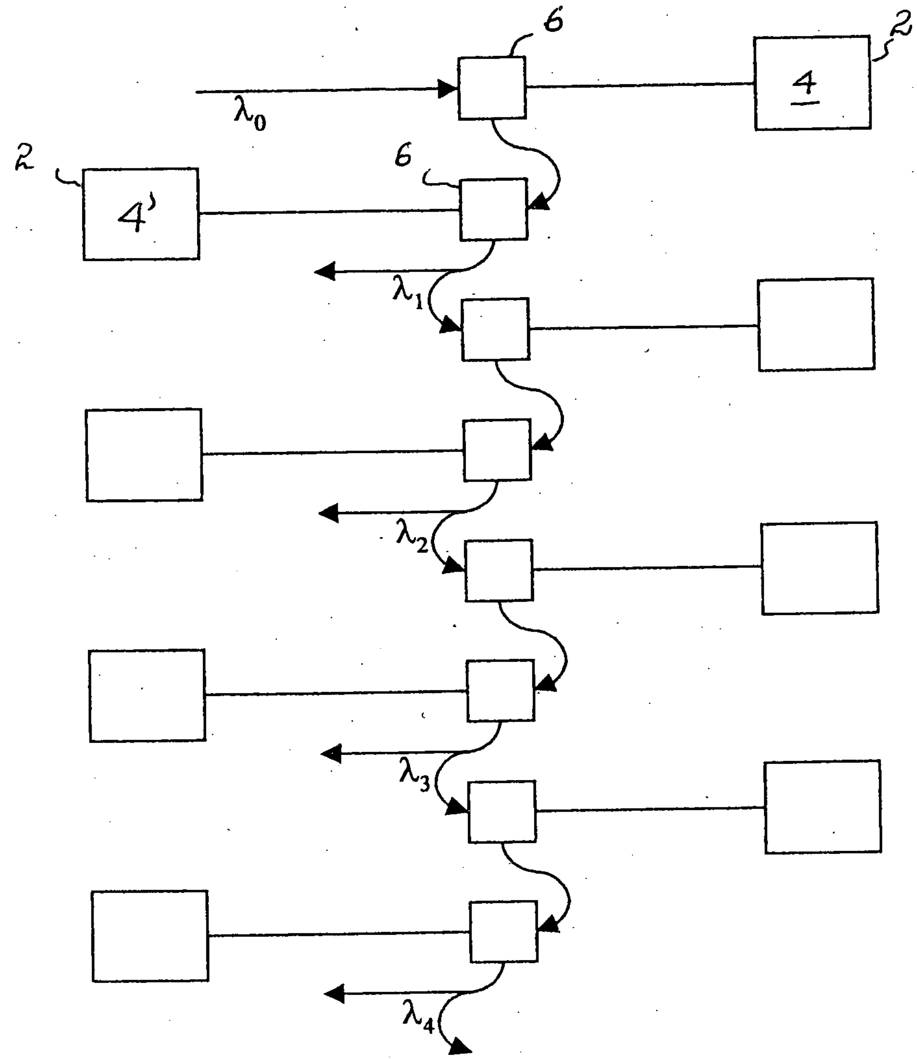
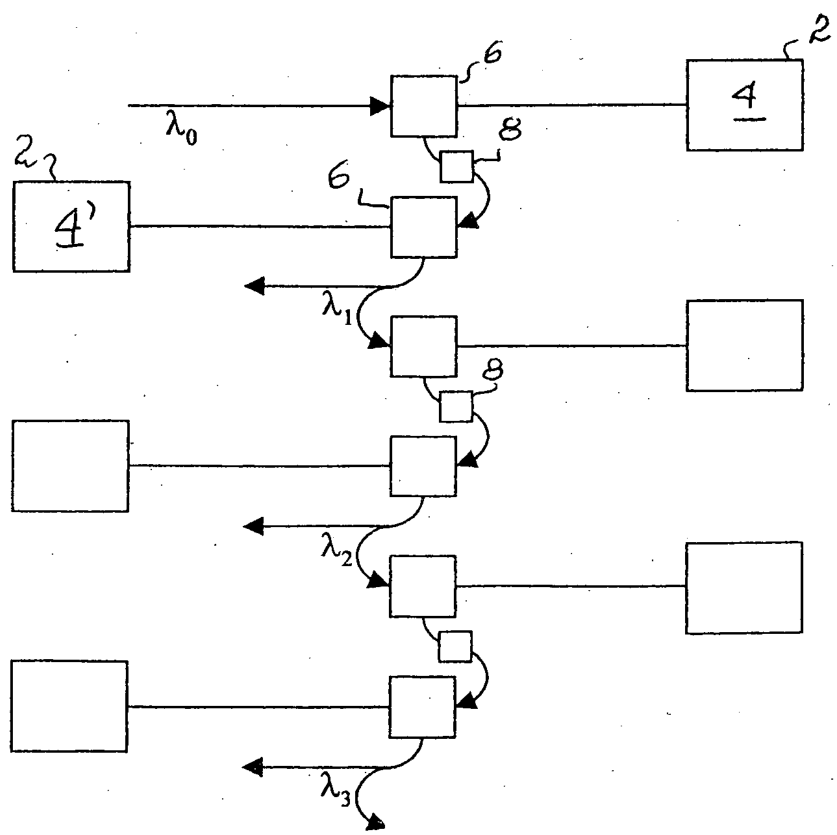

6
2
4
λ_0
2
6
4'
λ_1
λ_2
λ_3
λ_4

Fig. 5


6
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6
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λ_3

Fig. 6

Fig. 7

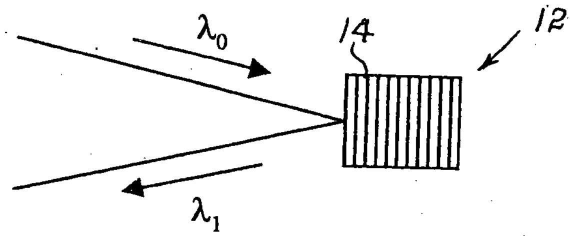
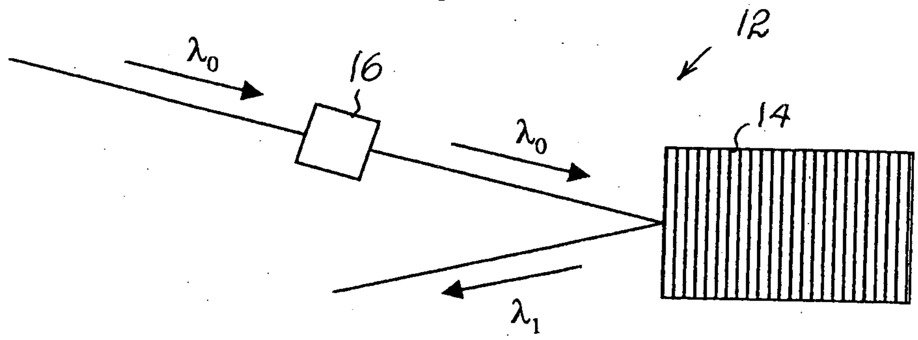


Fig. 8



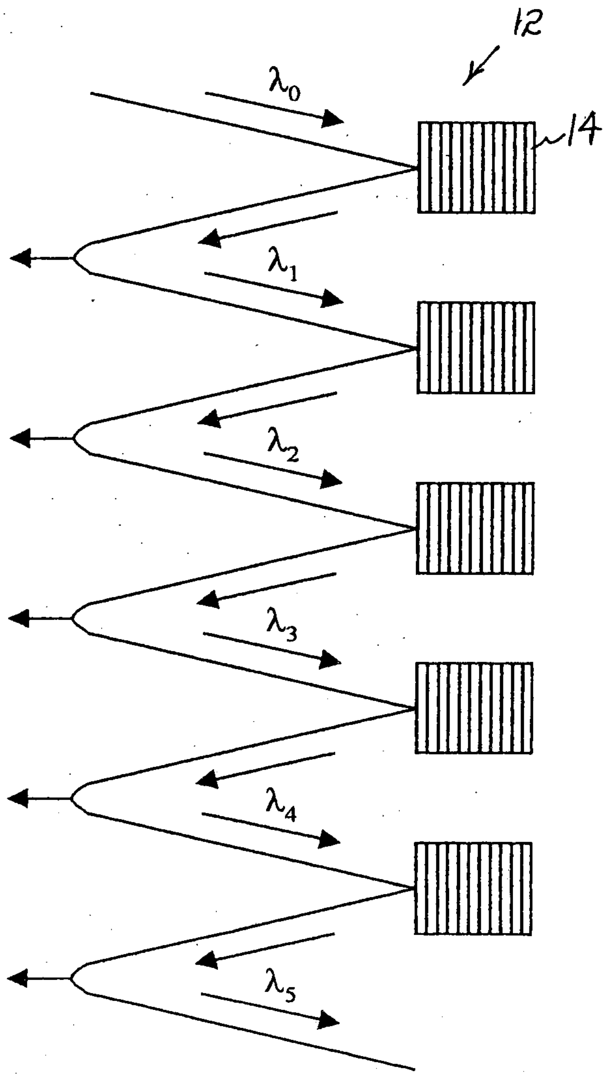


Fig. 9

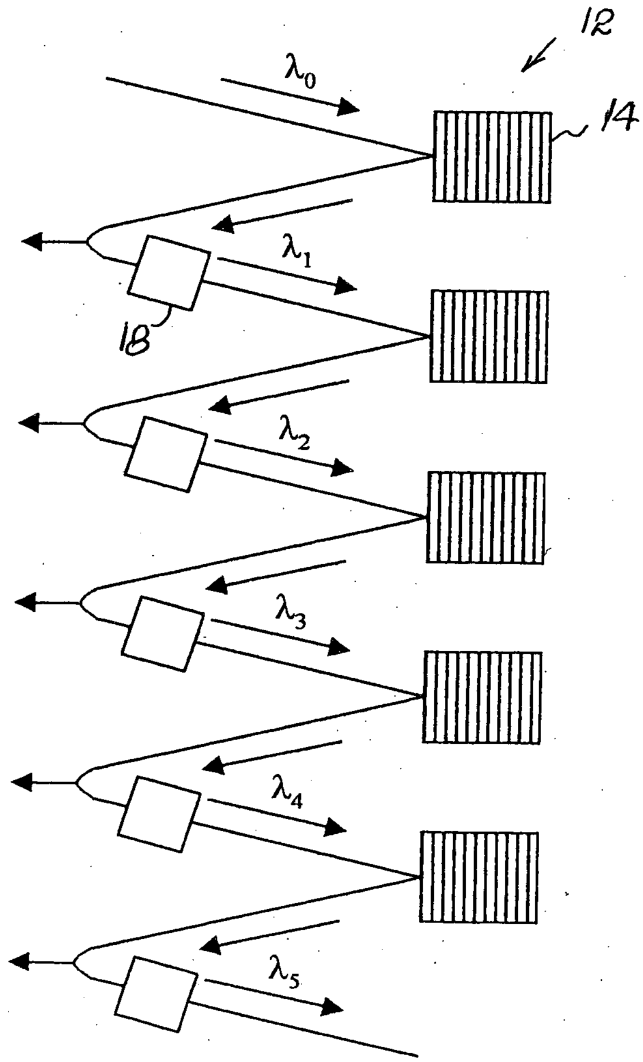


Fig. 10

Fig. 11

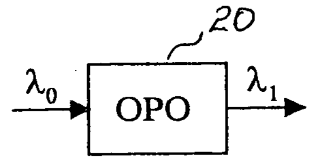


Fig. 12

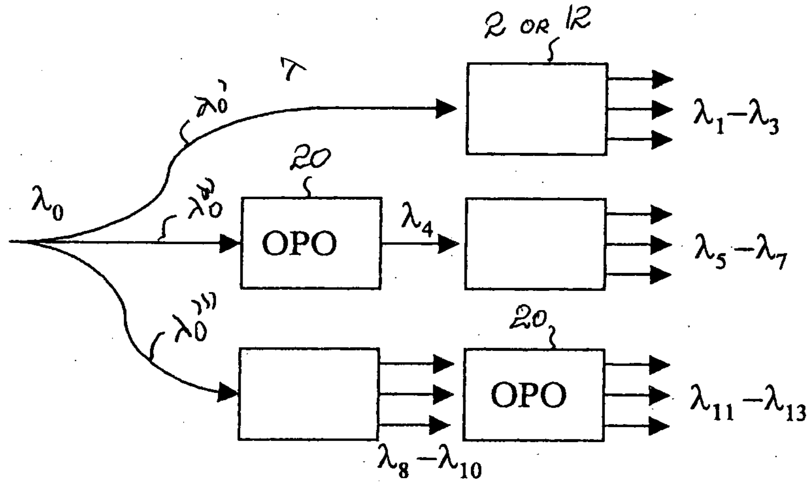


Fig. 13

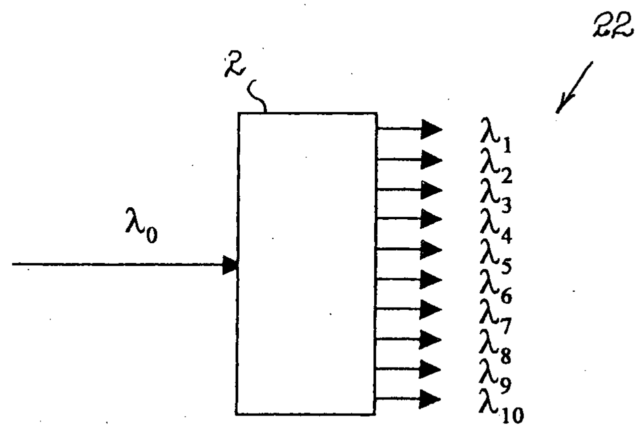


Fig. 14